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VOLUME I

Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

Session 3 - Optimisation and Management of Complex Systems and Networked Systems

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff Rector, TU Ilmenau	Professor Christoph Ament Head of Organisation

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A. Zangrilli / A. Picini

Unmanned Marine Vehicles working in cooperation: market trends and technical requirements

ABSTRACT

This paper provides a preliminary overview of an on-going market survey on Multiple Unmanned Marine Vehicles (MUMVs), developed in the framework of the GREX project. GREX is a R&D initiative supported by the European Commission aimed at the development of middleware systems to coordinate groups of heterogeneous unmanned marine vehicles working in cooperation.

1. GREX PROJECT

Autonomous vehicles applications have been growing very fast over the last few years following the advent of new innovative technologies which provide high levels of autonomy and reliability. The past decade has witnessed the emergence of autonomous behaviours in single mobile systems, with applications to the safe operation of ground, air, and marine vehicles in the presence of changing and unknown environmental conditions. The experience which has been acquired is now steadily being brought to bear on the solutions of far more complex problems that arise when multiple systems must work together. This shift of attention was brought about by the introduction of the concept of multiple autonomous vehicles performing missions cooperatively as an attractive alternative to the traditional single vehicle paradigm.

In this context the GREX project [1] aims to create a conceptual framework and middleware system to coordinate a group of diverse, heterogeneous robotic vehicles working in cooperation to achieve a specific goal. A selected number of methodologies and systems developed under the GREX project will be validated through testing them in real situations with Unmanned Marine Vehicles including Autonomous Underwater Vehicles, Remotely Operated Vehicles and Unmanned Surface Vehicles. To summarize, the project will develop technological solutions that will allow for the execution of complex missions using Multiple Unmanned Marine Vehicles (MUMVs).

In order to develop a "market-driven" product, the project includes a survey to monitor and to investigate current and future market trends as well as the technical requirements in the field of MUMVs. In the following sections the methodology used for carrying out the survey and the main results achieved until now are shown.

2. METHODOLOGY

The methodology followed to perform the survey consisted of four steps:

i. Data collection to gather information on MUMVs state of the art technology and market trends through literature research;
ii. Creating a questionnaire in order to collect information from experts worldwide belonging to companies and R&D organizations involved in the use and the development of Unmanned Marine Vehicles;
iii. Direct research through expert interviews; 95 organizations were contacted from which 16 interviews were collected;
iv. Final report drafting processing the data collected from the literature research and the results of the direct research. Although the survey is on-going, the information collected thus far allows us to provide a preliminary overview of the results.

3. MAIN RESULTS

The results shown below have been mainly extracted from interviews and are grouped in four parts:

i. An overview of existing initiatives focusing on development of solutions for MUMVs management and coordination;
ii. Benefits expected from the use of MUMVs;
iii. MUMVs – User needs;
iv. MUMVs - Market trends.

- **Overview of existing MUMVs initiatives**

The unmanned robots technology has gained a significant interest among a wide set of organisations operating in the marine domain due to its increasing reliability and cost effectiveness. Latest technology developments focuses on multiple vehicle approach potentially offering advance capabilities for applications including ocean sampling, mapping, surveillance and communication. So the use of multiple vehicles for defined tasks is currently an important topic within civil and military robotic research even if all attempts are still in their infancy [2]. Here a short description of some active initiatives follows:

i) *Seaswarm Pty Ltd* commercializes autonomous underwater swarming vehicles for highly efficient and rapid data collection and profiling of water and ocean bodies. The swarming concept is implemented through the use of small autonomous submarines designed to be deployed in a fleet [3].

ii) *The project "Decentralized Control of Multiple Autonomous Underwater Vehicles"* develops a comprehensive design procedure for communication among, and decentralized control of, a fleet of AUVs. Communication and distributed control concepts for a fleet of cooperating AUVs is investigated [4].

iii) *The project CADRE - Cooperative Autonomy for Distributed Reconnaissance and Exploration* develops a framework for the coordination of heterogeneous collections of unmanned vehicles for autonomous execution of goal-oriented missions [5].

iv) *The Multiple Cooperating AUVs (MCAUV) program* whose goal is to evaluate a Long Endurance Mobile Underwater Coastal Surveillance System through the development of innovative technologies focused on communication and cooperation multiple heterogeneous AUVs [6].

v) *The project ASAP - Adaptive sampling and prediction* whose goals are: learn how to deploy, direct and utilize autonomous vehicles (and other mobile sensing platforms) most efficiently to sample the ocean, assimilate the data into numerical models in real or near-real time, and predict future conditions with minimal error [7]. During the experiments led in the Monterey Bay 2006 field program the scientists have also studied how fleets of gliders can travel in different "formations" to cover hundreds of cubic kilometres of constantly evolving ocean [8].

- **Benefits expected from the use of MUMVs**

The MUMVs could have different advantages in a mission execution; interviewees were provided with a list of benefits in using MUMVs and they were asked to mark each one by level of importance. The following table shows the results.

BENEFITS EXPECTED	Score*
Mission time reduction	**63%**
New capabilities development	**51%**
Improvement of mission execution reliability	38%
Cost reduction for mission execution	25%
Optimisation of your existing vehicle "fleet"	14%

**Opinions were graded by a number from 1 to 6: 1= not relevant; 6= very important*
Score is the ratio between: the number of answers with "5" or "6" divided by the number of total answers

More than half of the interviewees cited the *mission time reduction* and the *development of new capabilities* (meant as new underwater tasks) as being the most **important** benefits in the use of MUMVs.

- **MUMVs – User needs**

To support the project technical partners in the development of a market-driven product, interviewees were asked to identify the **functionalities** and the **technical requirements** that a GREX-like system would be able to offer in a multiple vehicle scenario. Interviewees were provided with a list of features and they were asked to indicate the level of importance for each one.

The majority of functionalities listed in the table below were rated high priority by the respondents; in particular, the experts interviewed clearly indicated: *(i) mission re-planning, (ii) execution of downgraded mission and (iii) the monitoring of the state of the health of distributed systems* as the key functionalities to be implemented in a system for multi-vehicle applications.

SYSTEM FUNCTIONALITIES	Score*
Re-planning mission of the complete fleet in case of a new/modified objective	**75%**
Partially execution of the mission even in a downgraded situation	**75%**
Monitoring the "state of health" of the distributed communications and navigation system	**75%**
(Semi-) autonomous management capability for multiple vehicles mission execution	69%
Programming multiple-vehicle-missions using a single, central planning station	63%
Sharing sensor information inter-vehicles	44%
Common measure of mission execution status as the mission unfolds	31%

**Opinions were graded by a number from 1 to 6: 1= not relevant; 6= very important*
Score is the ratio between: the number of answers with "5" or "6" divided by the number of total answers

When considering the technical requirements three of them were clearly indicated as the most important (see table below): a system managing MUMVs is required to (*i) ensure the interoperability among the different acoustic modem systems, (ii) incorporate adaptive fleet formation capability in response to unforeseen events and (iii) ensure a full compliance with existing systems regarding user-interface.*

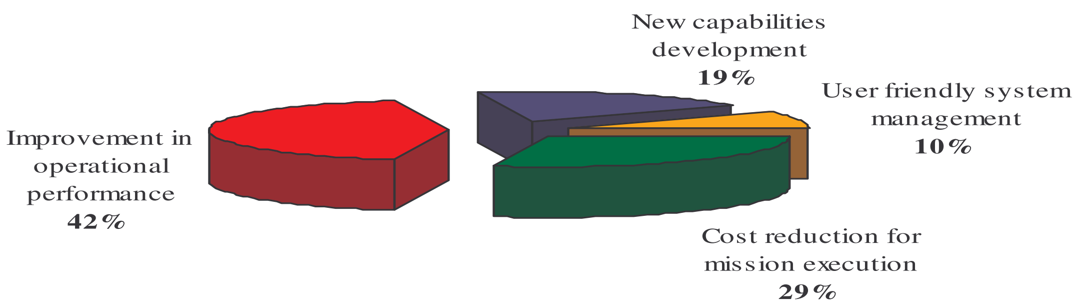
SYSTEM TECHNICAL REQUIREMENTS	Score*
User-Interface	
Compliance to link to existing programming systems for individual vehicles	**50%**
Using a single programming system for multiple heterogeneous vehicles	47%
Using graphical languages for programming	40%
Middleware/hardware for inter-vehicle communication	
Interoperability among different acoustic modem systems	**71%**
Seamless re-configuration of inter-vehicle communications network	43%
Constant monitoring of the status of the inter-vehicle communication network	43%
System for coordinated control of multiple objects	
Adaptive fleet formation capability in response to unforeseen events	**67%**
Tight fleet formation control as determined by a pre-defined strategy	29%

**Opinions were graded by a number from 1 to 6: 1= not relevant; 6= very important*
Score is the ratio between: the number of answers with "5" or "6" divided by the number of total answers

- **MUMVs - Market trends**

Considering the market expectations, 37,5% of the interviewees predict that MUMVs applications will rise **significantly** over the **next three** years. The reasons for positive answers were: the ability to conduct increasingly complex missions, limited only by software and not by vehicle hardware, and the improved cost efficiency in offshore surveys. It is envisaged that such features will be required mainly by oil & gas operations, port protection and deepwater and military applications. However, the majority of respondents (62,5%) consider the market to still be in its developing stages. The main concerns were: MUMVs applications could be too expensive and there is the need for a lot of R&D (5-10 years) before MUMVs applications become really operational. These concerns are supported by the fact that, as shown in Figure 1, the majority of interviewees (42%) indicated *"improvement in operational performance"* the most important factor that will affect the MUMVs market development, followed by *"cost reduction through the use of cheaper MUMVs"* (29%).

Figure 1 The most important factors allowing for MUMVs market development.



Although a significant market growth in the short term is not foreseen, the majority of respondents (64%) thought that generic and modular (GREX-like) systems for MUMVs mission planning and execution could be adopted by existing Unmanned Marine Vehicles by both manufacturers and users. However, some interviewees pointed out that the market is not yet mature enough to adopt open solutions since *”manufactures are unlikely to welcome open solutions and customers currently place a premium on reliability best demonstrated by closed systems”.* In that respect, customers should *“create the incentive for manufacturers to adopt a generic system”*.

4. CONCLUSION

There is a growing interest in developing systems for multi-vehicle management and coordination in order to carry out missions with increasing complexity; that is witnessed by many R&D projects existing worldwide. GREX contributes to this trend by developing software solutions for multi-vehicle coordination starting from the real needs of the market in terms of technical and functional requirements. These are being collected from a direct survey involving a majority of robotic underwater experts worldwide.

From the initial results of the survey, it has emerged that the market for MUMVs applications is still immature and further R&D efforts are needed to prove that they will be really operational. However, many respondents provided positive feedback on market potential of the generic and modular (GREX-like) systems, confirming the value of the GREX project.

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